BBC RD 1988/5

BBC

Research
Department
Report

June 1988

THE DEVELOPMENT OF PROTOTYPE ABSORBERS WITH VARIABLE CHARACTERISTICS

E.W. Taylor, M.A. (Cantab.), C.Eng., M.I.E.E., K.F.L. Lansdowne, and
R.J. Peill, B.Sc.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

BBC RD 1988/5

THE DEVELOPMENT OF PROTOTYPE SOUND ABSORBERS WITH VARIABLE CHARACTERISTICS

E.W. Taylor, M.A. (Cantab.), C.Eng., M.I.E.E., K.F.L. Lansdowne, and R.J. Peill, B.Sc.

Summary

The development of two prototype sound absorbers with controllable absorption characteristics is described. One of these absorbers gives control of sound absorption at predominantly low frequencies (up to 250 Hz), while the other operates at frequencies above this value. The low-frequency absorber is constructed in modular form, while the high-frequency absorber takes the form of a false ceiling to the treated room. Factors which are required to ensure the consistency of the absorption characteristics given by these absorbers are discussed.

Issued under the Authority of

M.E.B. Moffat

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

(PH-291)

June 1988

© British Broadcasting Corporation

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior permission.

THE DEVELOPMENT OF PROTOTYPE SOUND ABSORBERS WITH VARIABLE CHARACTERISTICS

E.W. Taylor, M.A. (Cantab.), C.Eng., M.I.E.E., K.F.L. Lansdowne,
and R.J. Peill, B.Sc.

1. Introduction 1
2. Controllable High-frequency Absorber 1
  2.1 The false ceiling 1
  2.2 Design and performance of prototype absorber 2
3. Controllable Low-frequency Absorber 5
  3.1 Design considerations 5
  3.2 Design and performance of prototype absorber 5
4. Discussion 7
5. Conclusions 9
6. References 10

THE DEVELOPMENT OF PROTOTYPE SOUND ABSORBERS WITH VARIABLE CHARACTERISTICS

E.W. Taylor, M.A. (Cantab.), C.Eng., M.I.E.E., K.F.L. Lansdowne, and R.J. Peill, B.Sc.

1. INTRODUCTION

This Report discusses the design of sound absorbers having variable absorption characteristics, which were developed during the design of a studio for the performance of music over the complete range from "classical" to "pop" and by a number of musicians from around four up to forty or perhaps even more. Ideally, differing types of music require a different acoustic environment for their performance, and this consideration suggested the provision of "variable acoustics" (an ability to change the sound absorption, and therefore the reverberation time, to suit the music being performed). This facility would also have enabled changes to be made in the sound absorption to compensate for the number of people in the studio, which could have been a significant factor for the larger numbers of performers envisaged.

In simple terms, the required change in sound absorption may be achieved by treating part of the surface (the ceiling, for example) with material of high absorption, and arranging that this can be covered by moveable panels (the "false ceiling" in the above example) of low absorption to increase the reverberation time. This approach has the disadvantage that an increase in reverberation time corresponds with a reduction in the volume of the studio. Attempts to provide a long reverberation time in an enclosure of small volume can lead to problems of tonal coloration, and a psychological conflict between two factors: the relatively slow sound decay on the one hand, and the pattern of sound reflections typical of a small and usually relatively non-reverberant room on the other. In the present case the volume of the studio was only 1065 m^3, even in the absence of the false ceiling, falling to 804 m^3 with the false ceiling in place (the large void above the false ceiling was required to accommodate ventilation ductwork). An alternative approach was therefore studied, in which the false ceiling carried sound absorbing material on its lower surface. Moving the false ceiling into place then simultaneously introduced extra absorption and reduced the volume of the studio. In this way the concept of the false ceiling was retained, but the condition of short reverberation time now corresponded to the condition of smaller studio volume.

The most practicable form of acoustic treatment for the false ceiling was a layer of porous material applied directly to its lower surface. This form of treatment provides predominantly mid- and high-frequency absorption, the low-frequency cut-off point of the absorption characteristic being determined by the thickness of the porous blanket. Controlled variation of the low-frequency absorption in the studio, in step with the movement of the false ceiling, was therefore also required in order to achieve a reasonably flat reverberation-time characteristic under both the long and the short reverberation-time conditions. A design of "modular" low-frequency absorber (i.e. an absorber in the form of a box of a standard size, which can be prefabricated away from the building site) was developed, whose characteristics could be controlled by covering or uncovering the front of the absorber (see Section 3). With the addition of some conventional (non-variable) acoustic treatment to give appropriate absorption at the longer reverberation time, it was thought that satisfactory overall absorption characteristics could be achieved in this way to give "short" and "long" reverberation times of 0.6 sec and 1.2 sec respectively.

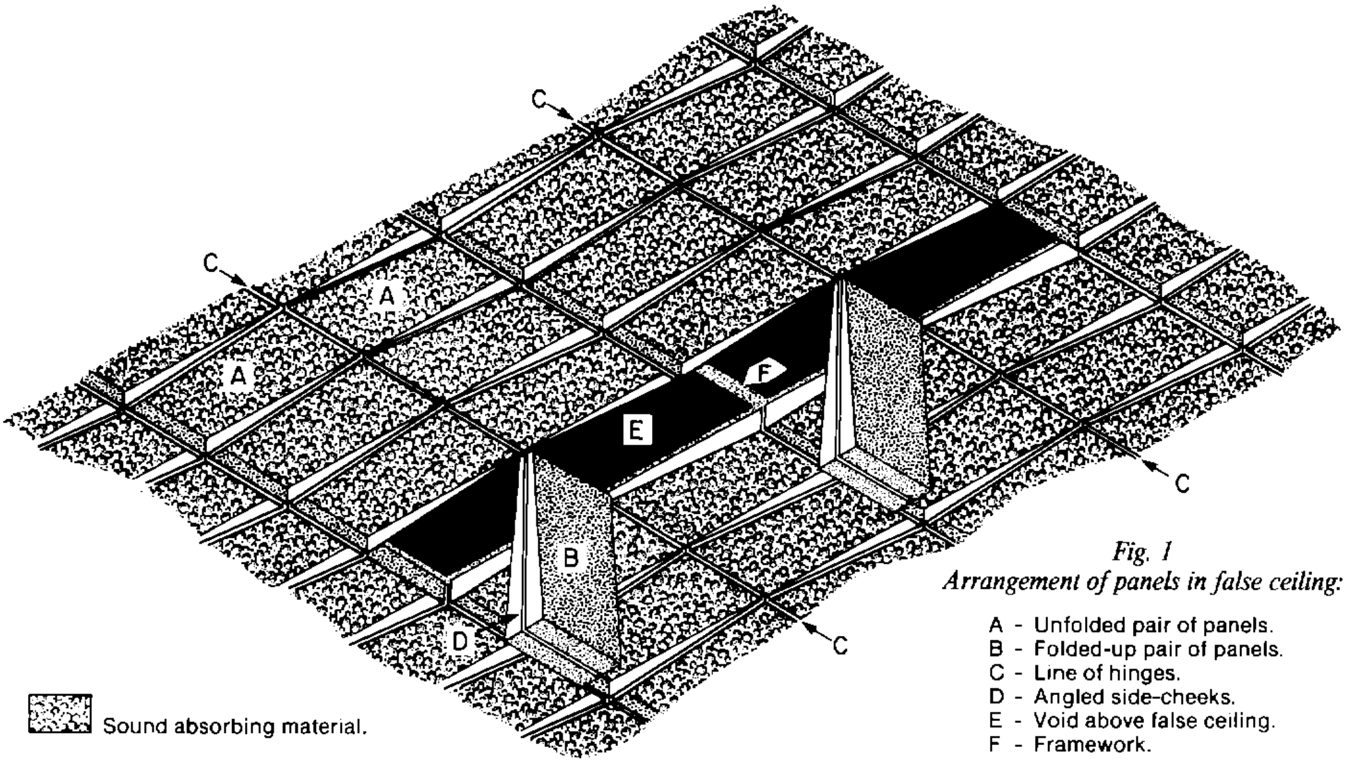
In the event, the idea of providing variable acoustics in this particular studio was abandoned and the possibility of testing the overall design concept was therefore lost. Nevertheless, the factors involved in the design and construction of the separate high and low-frequency absorbers were investigated in detail, and form the subject-matter of this Report.

The absorption coefficient measurements described in this Report were made using the conventional reverberation-room procedure[1]. The volume of the reverberation room was 106 m^3. This is rather small for reliable measurements below about 200 Hz[2a] because of the comparatively wide spacing of modal frequencies below this value. In the development of the low-frequency controllable absorber, discussed in Section 3, this limitation was a disadvantage although it was still possible to compare results obtained using different absorber design details. Some departure of practical absorber performance from that predicted by the test results may, however, occur, particularly if the absorbers are used in a room of much greater volume than the one in which they were measured.

2. CONTROLLABLE HIGH-FREQUENCY ABSORBER

2.1 The false ceiling

The false ceiling was designed as an array of panels (Fig. 1), the underside of each panel being covered with a blanket of absorbing material. In this design, pairs of panels were hinged together (not shown in detail in Fig. 1) and arranged so that they could be "unfolded" to expose the absorbing material or "folded up" to obscure it. Two of the panel pairs are shown folded up in Fig. 1, the rest being unfolded. Angled side-cheeks were to be provided on each panel, so that when folded up the hard surfaces of the panel pairs did not hang parallel to each other: this was to avoid any possibility of tonal coloration in the studio caused by multiple reflections between the panels. The means by which the panels would be folded up and unfolded was not considered in detail, although one possibility would have been cables attached to the panels and actuated by small winches. The whole structure was to be stabilized by an open framework which carried the hinges between pairs of panels, and which provided apertures against which the panels fitted when they were unfolded.



▨ Sound absorbing material.

Fig. 1
Arrangement of panels in false ceiling:

A - Unfolded pair of panels.
B - Folded-up pair of panels.
C - Line of hinges.
D - Angled side-cheeks.
E - Void above false ceiling.
F - Framework.

2.2 Design and performance of prototype absorber

Four prototype pairs of absorbing panels were constructed to investigate the sound absorbing properties of the false ceiling. Each panel (Fig. 2) was made of ¾-inch (19 mm) chipboard (except for the end member carrying the hinges which was made from wood for greater strength). The absorbing material, of dimensions 600 mm × 1200 m, was a blanket of "low-density" (50 $\mathrm{Kgm^{-3}}$) mineral wool 30 mm thick, retained by a welded steel grid mesh of ½-inch (12 mm) pitch. Ring bolts were provided near each corner of each panel so that they could be suspended from the ceiling of a reverberation room in either the unfolded or folded-up condition (Fig. 3).

Fig. 4 shows the sound absorption characteristics that were obtained with the panels suspended as described above, both unfolded (curve (a)) and folded up (curve (b)). In this context it should be noted that the same absorber area (that of the unfolded panels) was used in the calculation of the absorption coefficients in both cases, as this enables a direct comparison to be made of the overall absorption obtained under each condition. The effectiveness of the "folding absorber" design in controlling sound absorption above 200 Hz is immediately apparent.

The measurements of absorption coefficient with the panels in the folded-up condition were made with the gap where the side- and end-cheeks of the panels were nominally in contact sealed with adhesive tape. The importance of this precaution is shown in Fig. 5, which compares the absorption coefficients found with and without this seal (curves (a) and (b) respectively). Without the seal, the folded-up pair of panels tend to act as a resonant cavity absorber, perhaps with the resonant frequency influenced by the absorber structure as well as the mass of air inside the cavity. This gives rise to the enhanced absorption at low frequencies. In a practical implementation of this design it would be important to observe the precaution of sealing the gap where the folded-up panels meet.

The nature of the sound field in which the absorbers are placed can also influence the amount of

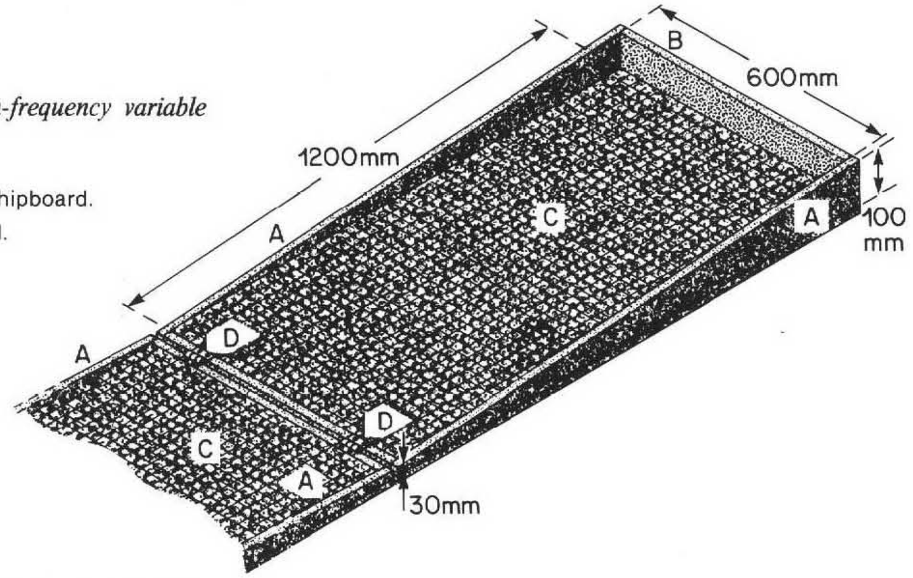


Fig. 2 - Construction of prototype high-frequency variable absorber.

A - Side-cheeks } 19 mm chipboard.
B - End-cheek
C - Rockwool under steel grid.
D - Hinges.

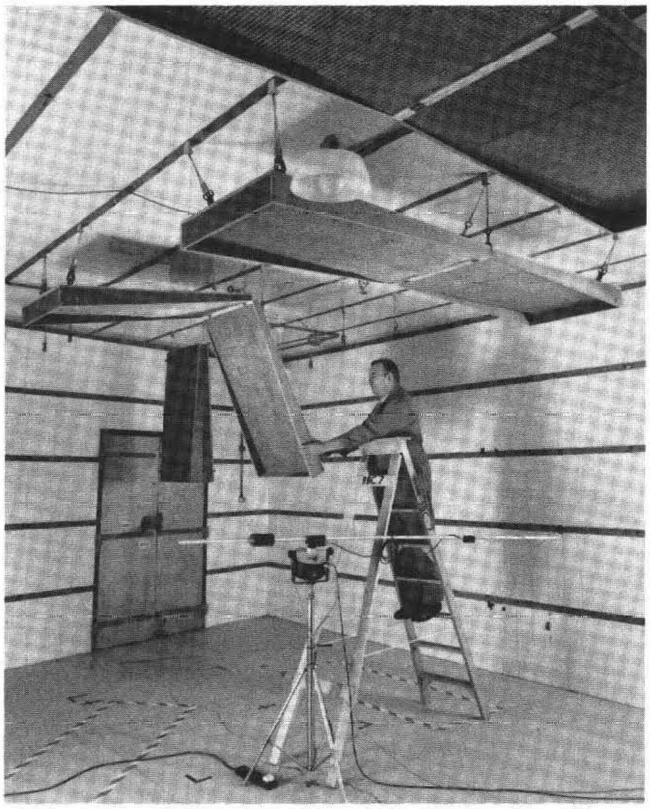


Fig. 3 - Absorbing panels suspended from reverberation-room ceiling.

absorption attained. To a first approximation, equal sound pressure exists at corresponding points on each side of the unfolded panels, when these are individually suspended from the ceiling as shown in Fig. 3. This is especially true at low frequencies, where the panel dimensions are small compared with the sound wavelength. Under these conditions the absence of differential sound pressure across the back of a panel would preclude its excitation, and it would therefore not contribute to the overall sound absorption. On the other hand, the complete false ceiling, with the panels unfolded, is intended to isolate the void above it from the rest of the studio. Under these conditions the sound pressure would be much greater on the underside of the panel than above it, with a correspondingly greater possibility of panel excitation. To test the significance of these different conditions, measurements were made with the panels supported on low plinths on the floor (Fig. 6). The gaps between the panels and plinths, and between the plinths and the floor, were again sealed with adhesive tape, thus protecting the back of the panel from the ambient sound field. Fig. 7 compares the results obtained under these conditions (curve (b)) with those found with the absorbers suspended from the ceiling (curve (a)). The absorption at low frequencies is very much greater (up to a factor of about five) when the sound field cannot reach the back of the absorber, suggesting that excitation of the back panel can be an important factor in the overall performance of the absorbers. This implies that it would be important to seal the gaps between the unfolded panels and the false ceiling support structure, in order to obtain a consistent differential sound pressure across the absorbing panels.

Although not strictly relevant to the present work, it is interesting to compare the absorption coefficient values obtained as described above with those found using the same conditions but without sealing the gaps between the floor, the plinth and the absorbers themselves (Fig. 8, curves (a) and (b) respectively). As in the case of the absorbers in the folded-up condition (see Fig. 5), the low-frequency absorption is very considerably increased when the gaps in the support structure of the absorbers are not sealed. It is noteworthy that this form of construction (a damped orifice leading into a cavity whose resonance is controlled largely by a vibrating panel) has been exploited in the design of a wideband modular absorber[3]. Such conditions should not

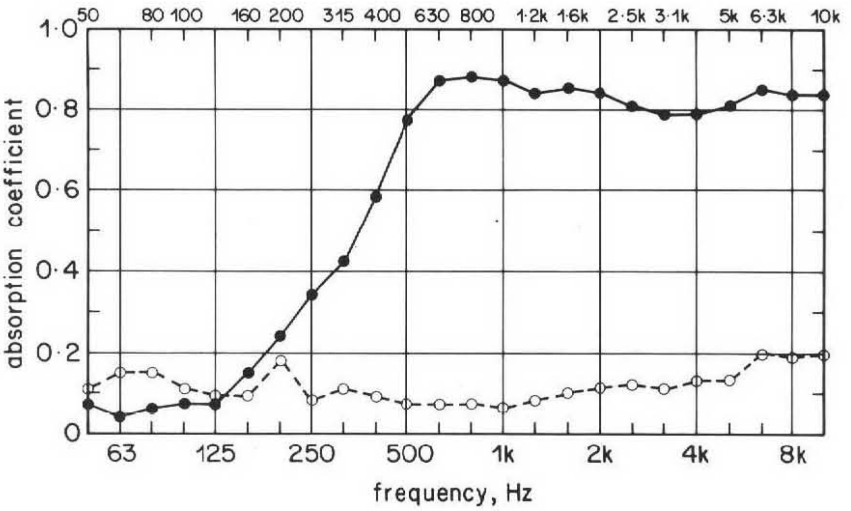


Fig. 4 - Results obtained with panels suspended from reverberation-room ceiling.

(a) ●—● Panels unfolded.
(b) ○– –○ Panels folded up.

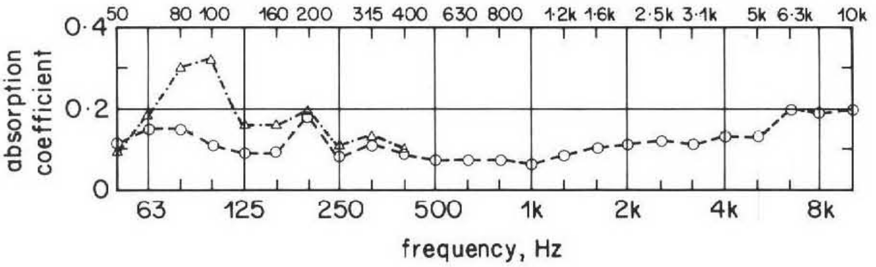


Fig. 5 - Effect of sealing gap between side- and end-cheeks of high-frequency absorber.

The curves do not differ significantly above 400 Hz.

(a) ○– –○ Seals present.
(b) △-·-·△ Seals absent.

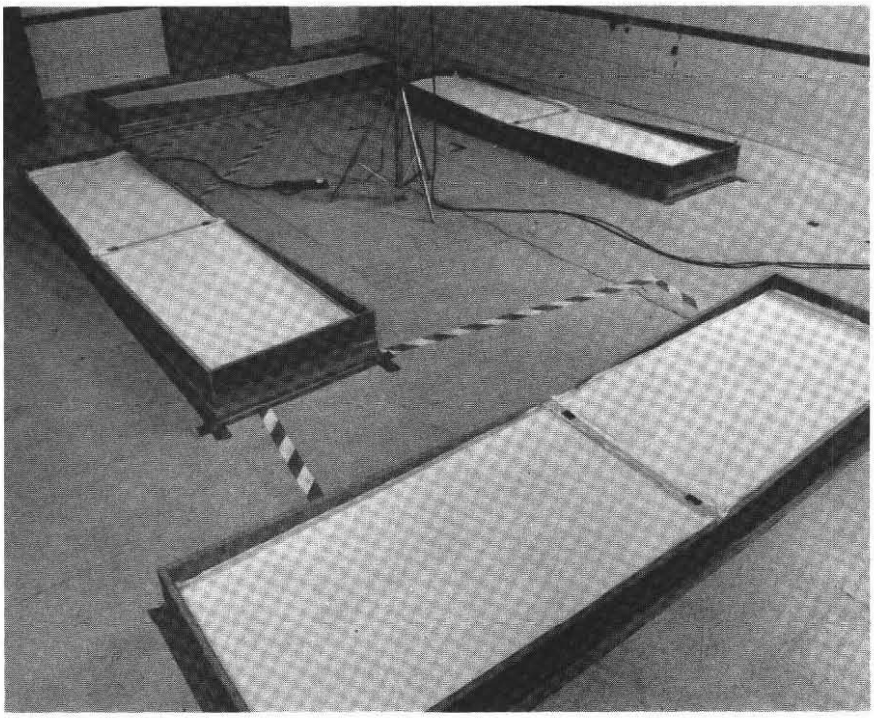


Fig. 6 - Absorbing panels supported on low plinths, on reverberation room floor.

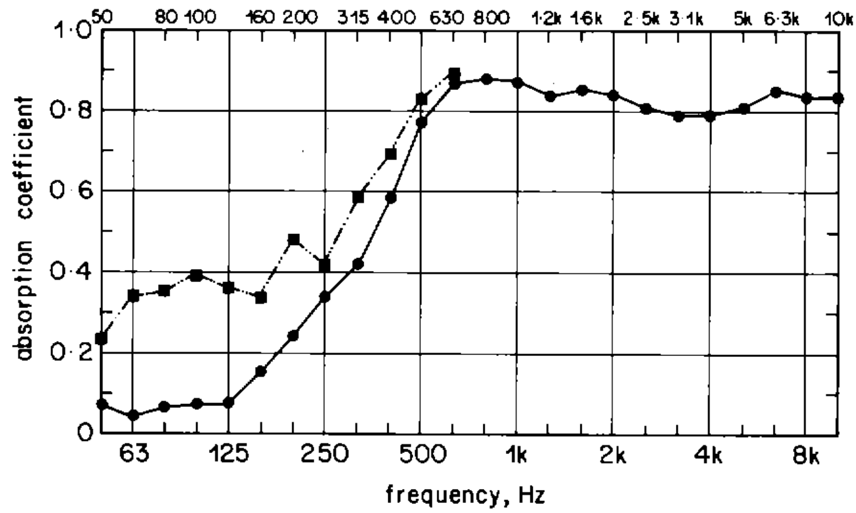


Fig. 7 - Effect of protecting backs of high-frequency absorbers from ambient sound field.

The curves do not differ significantly above 630 Hz.

(a) ●—● Backs exposed to ambient sound field.
(b) ■···■ Backs protected from ambient sound field.

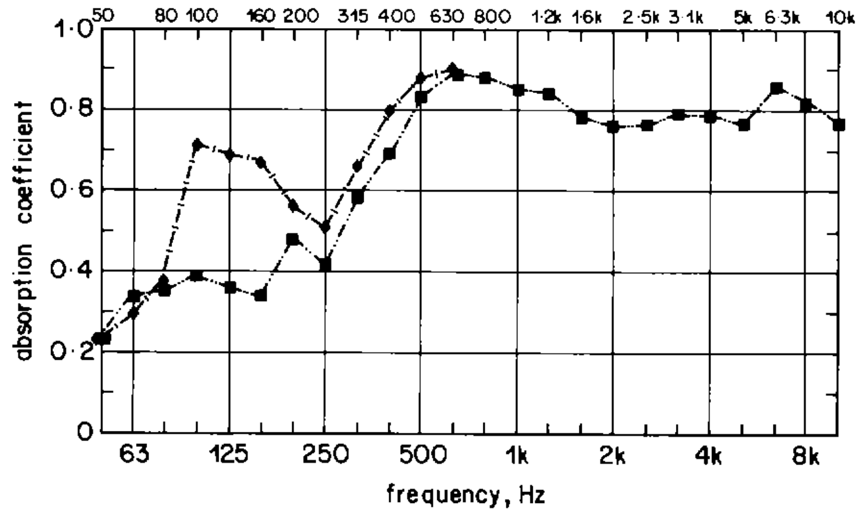


Fig. 8 - Effect of sealing cavity behind high-frequency absorber.

The curves do not differ significantly above 630 Hz.

(a) ■···■ Cavity sealed.
(b) ◆—·—◆ Cavity not sealed.

however be allowed to occur inadvertently, suggesting a further reason for sealing the gaps between the unfolded panels and the false ceiling support structure.

3. CONTROLLABLE LOW-FREQUENCY ABSORBERS

3.1 Design considerations

Inspection of Fig. 7 shows that a low-frequency absorption characteristic of the form shown in Fig. 9 is required to obtain the same absorption at all frequencies when the false ceiling is unfolded. The design which was adopted in the present case was based on the so-called "D2" modular absorber (a variant of the A2 modular absorber[4] with extended low-frequency absorption) as used in Studio 7, Manchester. With the false ceiling folded up, its absorption is low at all frequencies and ideally the low-fequency absorbers should then have similar characteristics. This was achieved by covering the front of the absorber with a panel of material having low absorption at all frequencies. It may be noted that the terms "absorber open" and "absorber closed" are used to denote the absence and presence of this panel respectively.

3.2 Design and performance of prototype absorber

The prototype low-frequency variable absorber module (Fig. 10) consisted of a box of internal dimensions 1790 mm long, 580 mm wide and 350 mm front-to-back. For reasons discussed below, this box was of rather massive construction: it was made of two layers of 25 mm (1-inch) chipboard bonded together, thus giving an overall surface density of 35 kg m^{-2}. Furthermore, no back panel was provided, and the box was sealed to the room surface on which it was mounted. A membrane of plain hardboard 3.2 mm (⅛-inch) in thickness was mounted 50 mm from the front edge of the box using a wood fillet, and this sheet was backed by a layer of low-density (50 kg m^{-3}) mineral wool 30 mm thick. The mineral wool layer was supported by an "egg-crate" structure (intersecting sheets of thin material with "halving"

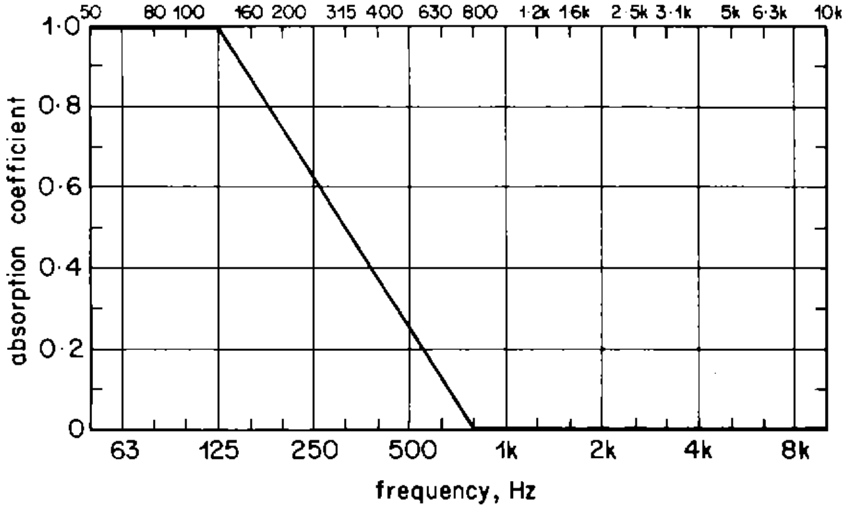


Fig. 9 - Absorption/frequency characteristic required for low-frequency absorbers.

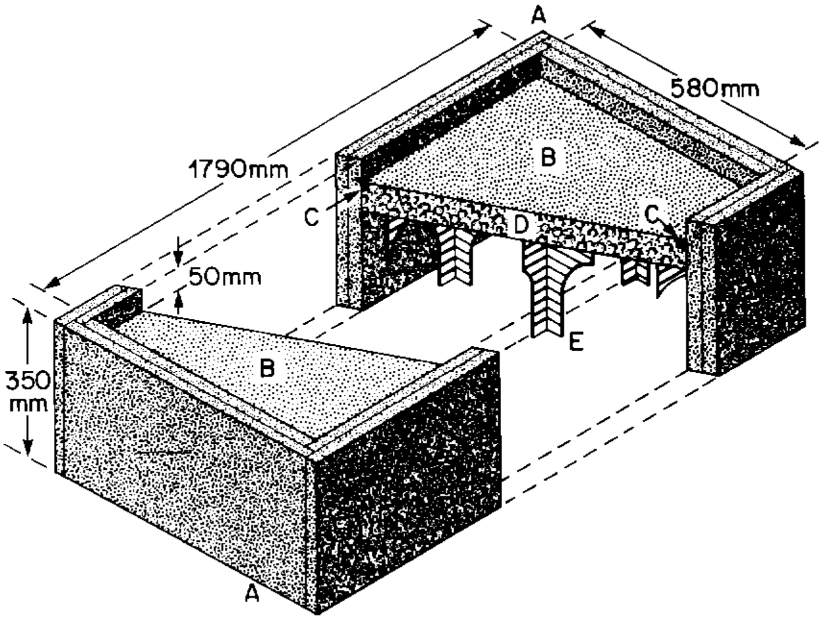


Fig. 10 - Construction of prototype low-frequency variable absorber.
(lid not shown: see text)

A - Walls: 2 × 25 mm chipboard.
B - Hardboard membrane.
C - Wood fillet.
D - Rockwool.
E - "Egg-crate" supports.

joints at the intersections), also made of hardboard, which was cut away so that the air-space under the mineral wool was effectively continuous over the whole module. The internal structure of the module can be seen in the rear view shown in Fig. 11.

The absorption of the module was controlled by a close-fitting front panel also made of two layers of 25 mm chipboard, but with the outer layer divided into six sections to increase the panel compliance and so lower its resonance frequencies. Both the box and the front panel were painted to block cracks or pores in the chipboard. Fig. 12 shows front views of two modules, one (left) with the front panel removed and the other (right) with it in place, while curves (a) and (b) of Fig. 13 show respectively the corresponding high-absorption and low-absorption characteristics. It may be noted that these characteristics were obtained using three absorber modules (total surface area approximately 3 m^2) in the reverberation room.

The massive construction of the absorber module was chosen because preliminary tests had confirmed earlier findings[5] that significant absorption takes place at the walls of a modular absorber. It was hoped that this type of construction would be sufficient to suppress this unwanted absorption, so that the required characteristics with the absorber closed could be obtained. Tests on an early design of the module, fitted with a back panel of 6 mm (¼-inch) hardboard, showed however that in the closed condition significant absorption occurred at frequencies between 200 Hz and 400 Hz: this can be seen in Curve (a) of Fig. 14. It was found that removing the back panel reduced this unwanted absorption considerably (Fig. 14, Curve (b)). It is possible that the back panel provided a "sink" for vibrational energy in the sides of the module, either by loss in the panel itself, or by forming a path, together with the compliance of the air inside the box, for transferring sound energy to the mineral wool layer behind the hardboard membrane at the front of the absorber (see Fig. 10). Considering the already massive construction of the module, it would appear that an even more solid form of construction (e.g. plastered brickwork) would be required to suppress still further absorption by the side panels.

Curve (b) of Fig. 14 also shows that some degree of absorption is present at low frequencies with the absorber closed, even when the back panel has been removed. This is probably due to excitation of the front panel by the ambient sound field, despite its massive construction: sound energy is again transferred to the mineral wool layer, this time by way of the compliance of the air between the front panel and the hardboard membrane, and the membrane itself. Again, a more massive construction would be required to reduce this absorption component still further.

Although not considered as part of the basic design, some attention was given to a practical method of opening and closing the absorber, bearing in mind the considerable mass of the front panel (about 40 kg). Fig. 15 shows a possible arrangement in which the front panel is lifted away from the face of the absorber but remains parallel to it. Tests were carried out to find the smallest distance between the absorber and the front panel which was consistent with satisfactory absorber performance. In these tests the front panel was moved away from the absorber without the vertical component of movement as implied in Fig. 15. The results of these tests are shown in Fig. 16: they show that, when compared with the front panel completely removed (Curve (a)), almost the full amount of absorption at low frequencies is obtained with only a 75 mm spacing (Curve (b)). At larger spacings (Curves (c) and (d)) the low-frequency absorption is in fact enhanced. The result obtained with a 300 mm spacing (Curve (d)) represents a rather better realisation of the stated low-frequency absorber requirements (see Fig. 9) than the condition with the front panel removed completely (Curve (a)).

Fig. 16 also shows that the proximity of the front panel increases the absorption at higher frequencies, and that this increase rises with panel-to-absorber spacing. Further tests showed that this rise is consistent with the progressively greater exposure of the unpainted (and therefore slightly porous) inside surface of the front panel.

4. DISCUSSION

The work discussed in Sections 2 and 3 has shown that it is feasible to construct sound absorbers in which the absorption coefficient can be changed between a higher and lower value either in the upper

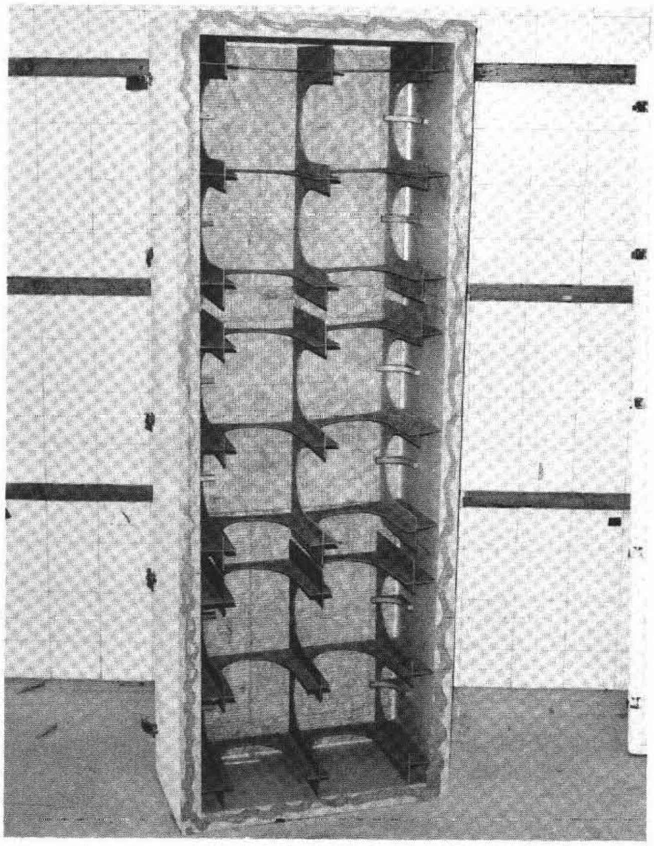


Fig. 11 - Rear view of variable low-frequency absorber module, showing internal structure.

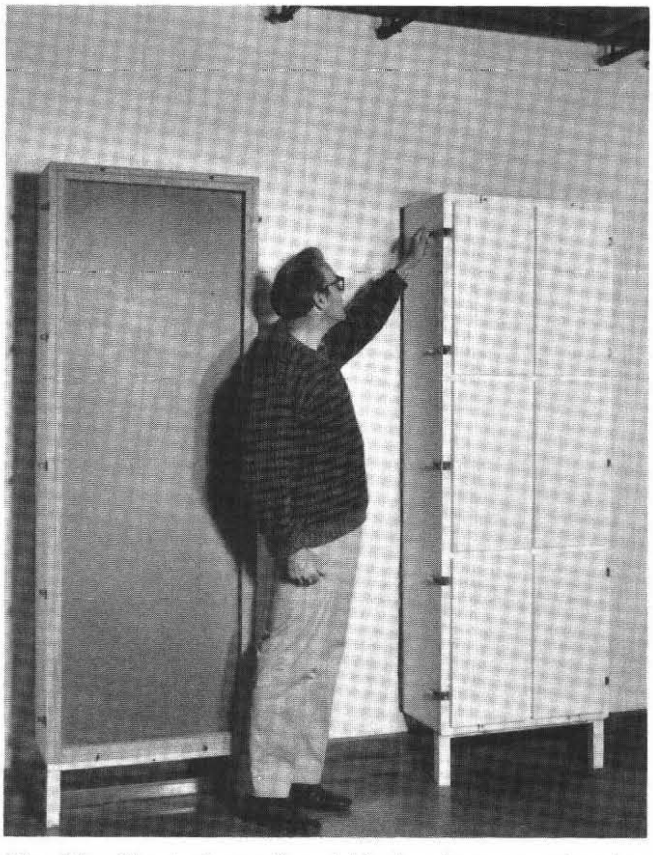


Fig. 12 - Front views of variable low-frequency absorber modules, with cover in place (right) and removed (left).

or lower part of the frequency spectrum. It has however not been found possible to "turn off" such absorbers completely when the condition of longer reverberation time is required in the treated room. In itself this factor should not present a serious problem, as some absorption will always be required to control the longer reverberation time, and the amount of treatment can be adjusted appropriately provided that the absorption of the controllable absorbers in their low-absorption condition is lower than the amount required for this treatment. However, this does imply that these "residual" absorption characteristics must be repeatable: careful attention must be paid, in particular, to the seals between components of a variable absorber in order to ensure this repeatability (see Section 2.2). In a structure such as the false ceiling of a studio, where access for maintenance may be difficult, this provision is of particular importance.

If a modular form of construction is used for the controllable absorbers, values of reverberation time between the highest and lowest specified values can in principle be obtained by selective control of the absorbers themselves. This is not however possible in the case of a structure such as the false ceiling described in Section 2. In the first place, the absorption characteristics depend on whether or not the rear of the absorbers are exposed to the sound field in their high-absorption condition (see Fig. 7). Furthermore, the acoustic design of a studio with a "solid" false ceiling presupposes that this ceiling will be either completely opaque or completely transparent to sound. The condition in which portions of the ceiling are open and the rest closed would resemble that of two communicating rooms with, perhaps, different reverberation times[2b]. In such cases non-exponential sound decay characteristics may be obtained which could affect the acoustic peformance of the studio. If a continuous variation in reverberation time was required in a studio, the "false ceiling" method of controlling sound absorption would not be practicable, and a studio of constant volume with

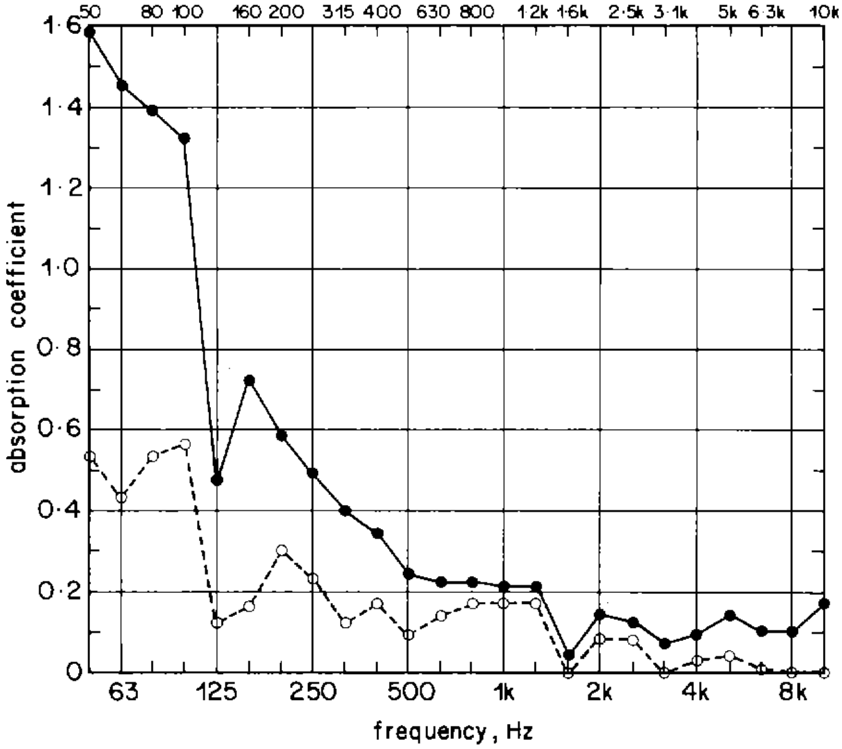


Fig. 13 - Absorption/frequency characteristics of prototype low-frequency controllable modular absorber.

(a) ●—● Cover removed.
(b) ○--○ Cover in place.

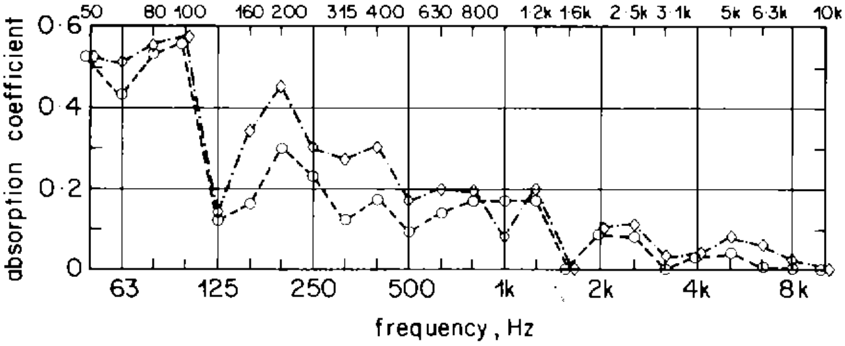


Fig. 14 - Effect of presence of back panel of low-frequency absorber, with front cover in place.

(a) ○-·-○ Back panel present.
(b) ○--○ Back panel removed.

controllable surface treatment would be necessary. High-frequency controllable absorbers of the type described in Section 2.2 could be used in this way simply by hanging them from the structural ceiling of the studio without leaving a void behind them.

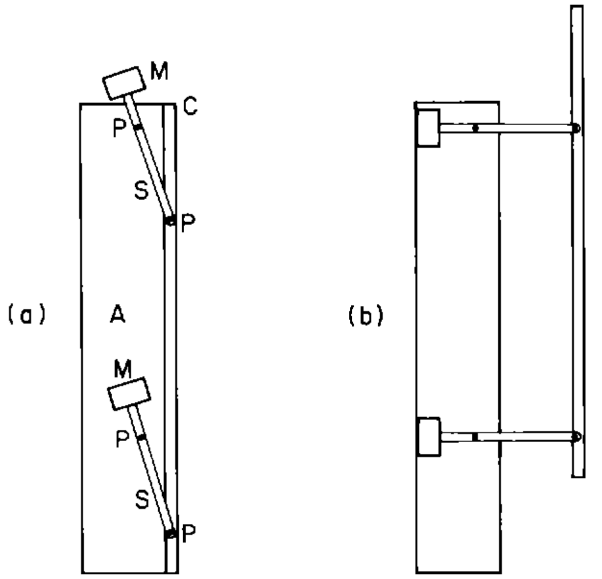


Fig. 15 - Low-frequency absorber with cover in place (a) and removed (b).

A - Absorber module.
S - Support.
C - Cover.
M - Counterbalance mass.
P - Pivot.

5. CONCLUSIONS

Two types of prototype absorbers have been constructed, in which the absorption coefficient can be changed from a high to a low value over part of the frequency spectrum. In one case absorption at the low-frequency end of the spectrum (50 Hz - 250 Hz) is controlled, while in the other case absorption at frequencies above about 250 Hz is controlled. Taken together, these absorbers could provide the basis for implementing a "variable acoustics" studio with a two-to-one change in reverberation time.

The absorbers controlling the higher frequencies were designed to be part of a "false ceiling" construction which was opaque to sound and had the effect of significantly reducing the volume of the studio. It was arranged that the condition of greater volume should correspond with the condition of lower absorption (contrary to normal practice), so as to minimize difficulties in attempting to provide a good acoustic environment in a studio of rather small volume. The absorbers controlling the lower frequencies were designed in modular form, to be attached to the studio walls.

In their "low-absorption" condition the actual sound absorption of the controllable absorbers was still significant. Since a degree of "fixed" absorption is in any case required, to control the longer reverberation time, this factor is not necessarily a disadvantage.

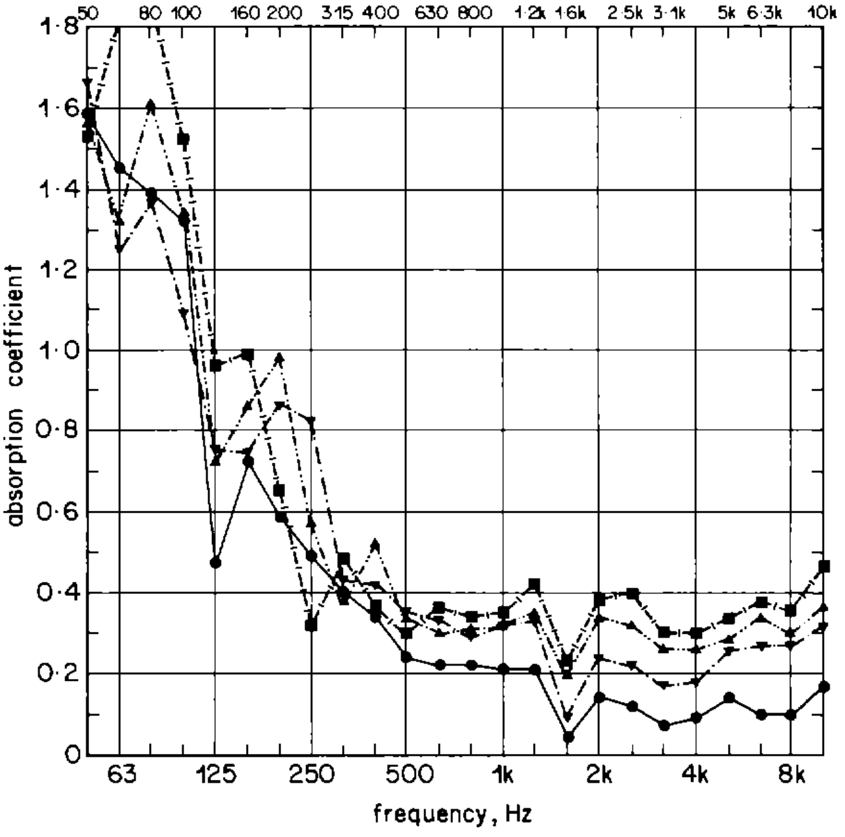


Fig. 16 - Effect of distance between cover and front of low-frequency absorber module.

(a) ●—● Cover removed completely.
(b) ▼-·-▼ Cover-absorber distance 75 mm.
(c) ▲···▲ Cover-absorber distance 150 mm.
(d) ■-··-■ Cover-absorber distance 300 mm.

However, the amount of residual absorption of the controllable absorbers in their low-absorption condition must remain at the same level: attention has to be paid to the absorber construction (in particular to the seals between the moving components) for this condition to be realized in practice.

If intermediate values of reverberation time are required in a studio, rather than fixed "high" and "low" values, the false ceiling approach to sound absorption control has to be considered with caution. The same absorber design can however be used, but with the absorbers fixed directly to the structural ceiling of the studio (or, indeed, to the walls) without a void behind them.

6. REFERENCES

1. GILFORD, C. Acoustics for Radio and Television Studios. Peter Peregrinus Ltd., 1972. pp 146-149.

2. KUTTRUFF, H. Room Acoustics. Applied Science Publishers Ltd., London, 1973.

   2a. Ibid., page 231.

   2b. Ibid., Section V.6.

3. WALKER, R. and LEGATE, P.H.C. The Design of a New Wideband Modular Sound Absorber. BBC Research Department Report No. 1982/8.

4. ROSE, K.A. Guide to Acoustic Practice. BBC Architectural and Civil Engineering Department publication, 1980. Fig. 24.

5. WALKER, R. and RANDALL, K.E. An Investigation into the Mechanism of Sound-energy Absorption in a Low-frequency Modular Absorber. BBC Research Department Report No. 1980/12.

Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP